



RESEARCH DEPARTMENT



REPORT

Permissible timing jitter in broadcast PAL colour-television signals

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PERMISSIBLE TIMING JITTER IN BROADCAST P.A.L. COLOUR TELEVISION
SIGNALS
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Summary

The report considers the results obtained from a number of different sets of subjective tests concerning tolerances for timing instabilities (referred to as jitter) in broadcast P.A.L. colour-television signals. The magnitude of the timing errors considered is of the order of a few nanoseconds. These errors produce perturbations in the saturation and hue of colour areas of a displayed picture. An attempt is made to identify the reasons for discrepancies between some of the test results, and limits are suggested for the maximum jitter which should be allowed in a broadcast signal. This work is particularly relevant to the video signals obtained from video-tape recorders and is also useful in assessing the performance of digital transmission links now in the experimental stage of development.

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PERMISSIBLE TIMING JITTER IN BROADCASTING P.A.L. COLOUR-TELEVISION SIGNALS

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PERMISSIBLE TIMING JITTER IN BROADCAST P.A.L. COLOUR-TELEVISION SIGNALS

V.G. Devereux, M.A.

1. Introduction

During the past few years, a number of different series of subjective tests have been carried out in the United Kingdom for the purpose of determining the maximum timing-perturbations or 'jitter' which should be allowed in broadcast P.A.L. television signals. This limit is almost totally determined by impairments to the reproduction of coloured areas caused by phase perturbations of the chrominance signal; the magnitude of jitter at which these impairments become visible is not sufficient to cause geometric unsteadiness of luminance information in a picture.

Permissible limits for jitter are of interest for both analogue and digital video-processing operations. In analogue operations, the most common source of jitter is video-tape equipment, while in digital operations the most likely sources of jitter are the digital regenerators employed in transmission links. In both cases, the jitter spectrum is unlikely to extend significantly beyond 1 to 2 kHz.

Four sets of subjective tests are considered, three of these having been carried out by the B.B.C. and one by the I.B.A. One of the main reasons for carrying out the work reported here is that there are significant discrepancies between some of the results obtained from different sets of tests. An attempt is made to analyse the reason for these discrepancies and acceptable limits for timing jitter are suggested which appear to be reasonably consistent with the results given by all the tests, after allowing for possible errors.

All the tests considered in this report were performed using delay-line (P.A.L._D) decoders.

2. Properties of P.A.L. decoding circuits affecting picture impairment caused by jitter

The degree of picture impairment caused by jitter depends to a large extent upon the alignment of the P.A.L. decoding circuits. The most important error likely to occur in the alignment of a P.A.L._D decoder is an incorrect adjustment of the static phase ' θ ' of the reference subcarrier applied to the colour-difference signal demodulators. With jitter-free video signals the effect of such an error is to cause a reduction in the output level of each demodulator according to a cosine law as shown in Fig. 1. As a result, the saturation of the colours in the display picture is reduced but, in broad terms, the hue is not affected. The effect can easily be compensated for by an increase in the chrominance gain. However, if the chrominance signals fed to the demodulators are jittering in phase with respect to the reference subcarrier, the magnitude of the resulting variations in the demodulated colour difference signals are increased in the presence of a static phase error, i.e.

V_j is greater than V_{j0} in Fig. 1. Moreover, re-adjustment of the chrominance gain to compensate for the static phase-error causes a further increase in the magnitude of these variations by a factor of $1/\cos \theta$. Fig. 1 shows that, when the static phase is correct, the variations in the colour-difference signals are at a minimum and the frequency of these variations is doubled compared to the frequency obtained with an incorrect static phase.

Theoretical calculations given in the Appendix, Section 11.1., indicate the amount by which the jitter magnitude should be reduced as the static phase error increases for a given peak-to-peak variation in the colour-difference signals. As an example, the calculations indicate that if the static phase error is changed from 0 degrees to 15 degrees, the magnitude of sinusoidal jitter should be reduced by at least 20 dB, i.e. by a factor of at least 10, in order to ensure that the impairment remains close to the threshold of visibility.

With a delay-line P.A.L._D decoder, the effect of jitter are further complicated because timing jitter in the video signal applied to the decoder can cause both hue and saturation variations in a displayed picture, the relative proportions of hue and saturation variations being dependent on the repetition frequency of the jitter. At repetition frequencies close to nf_L , where f_L is the line-scan frequency of the video signal and $n = 0, 1, 2$ etc, only saturation variations are obtained, the magnitude of these variations being dependent on the static phase of the reference subcarrier as discussed above. However, at repetition frequencies close to $(n + \frac{1}{2})f_L$, only hue variations are obtained and the magnitude of these variations is nearly independent of the setting of the static phase of the reference subcarrier. Further details of the effects of altering the jitter repetition frequency are given in the Appendix, Section 11.2.

In practice the spectrum of the timing jitter introduced by video equipment employed in a broadcasting network is mainly confined to frequencies below $f_L/2$ and, therefore, tests on jitter have been concentrated within this frequency range.

Other decoding errors that increase the impairment resulting from jitter include:

- (a) Decoding axes at the two colour-difference signal demodulators not in quadrature.
- (b) Incorrect delay in the chrominance line-period delay.
- (c) Gain error in the delay-line adder/subtractor.

These three types of error are generally less important than errors in the static-phase of the reference subcarrier

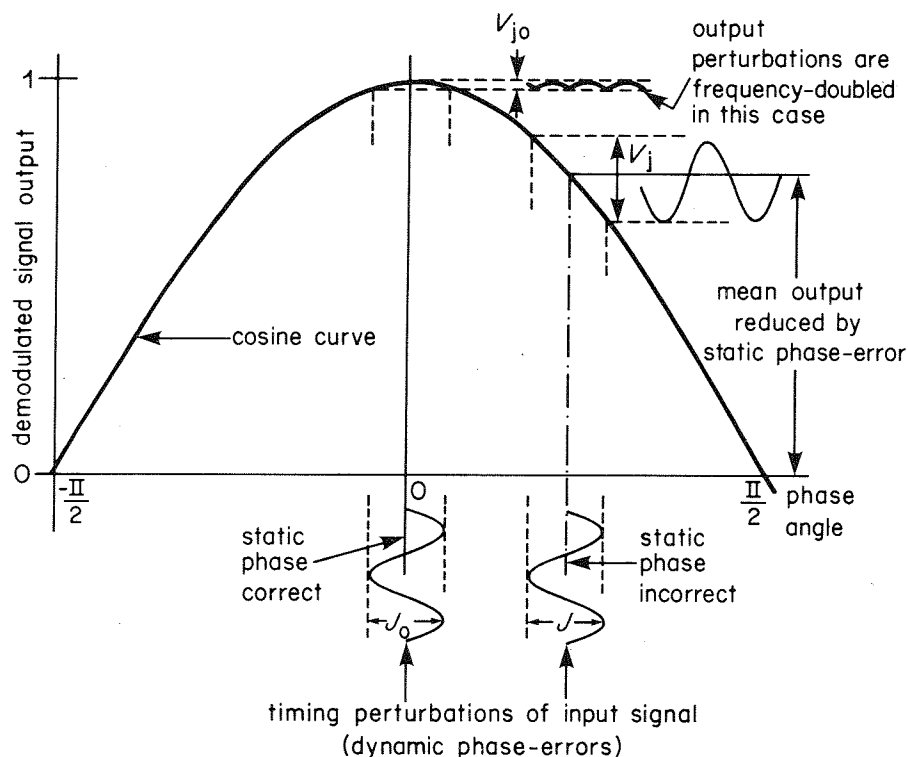


Fig. 1 - The combined effect of static and dynamic phase errors in a synchronous demodulator

but, nevertheless, could have a significant effect on results of tests on jitter.²

3. Factors affecting the permissible amount of very-low frequency jitter

Assuming the reference subcarrier used to demodulate the chrominance signal is locked to the original colour burst of the jittered video signal, the impairment caused by jitter progressively decreases as the jitter frequency decreases below about 100 Hz; as the jitter frequency falls below this value the burst-locked oscillator in the decoder is increasingly able to follow slow variations in the phase of the burst. However, in a broadcasting network, a stable colour burst is often re-inserted in a video signal and the permissible amount of very-low frequency jitter is then reduced; this situation normally applies to video signals obtained from video-tape recorders.

A third situation to be considered concerns jitter introduced in transmission links. If the video signal from the link is synchronised to a second video signal in order to enable operations such as video switching and mixing to be performed satisfactorily, the relative timing variations between the two signals caused by jitter in the link will be reduced by the action of the synchronising system.

With the slowest acting synchronising system now in use in the United Kingdom ('Natlock'), any very-low frequency variation in link transmission time will be reduced to negligible proportions if they do not change the phase of the colour subcarrier by more than 1.5° in 40msec. This leads to a specification that the peak-to-peak amplitude of sinusoidal jitter in a transmission link should not exceed $7.5/f$ ns where f is the jitter frequency in Hz; this specification does not apply to values of f above about 10 Hz.

4. Classification of previous tests

The previous series of subjective tests to be discussed are listed below.

(a) Test Series 1

These tests were carried out by the B.B.C. in 1972¹ and their main purpose was to investigate threshold limits for jitter introduced by a digital transmission system.

(b) Test Series 2

These tests were carried out by the B.B.C. in 1974² and their main purpose was to investigate threshold

limits for jitter introduced by analogue equipment, particularly video-tape recorders.

(c) Test Series 3

These tests were carried out by the I.B.A. in 1975.³ The objective of these tests was to review the results obtained from Test Series 2.

(d) Test Series 4

These tests were carried out by the B.B.C. in 1976. The results obtained have not been published previously. The object of these tests was to try and resolve some discrepancies between the results of Test Series 2 and 3.

5. Details of test conditions

The types of jitter examined were, first, sinusoidal timing perturbations mostly in the frequency range 0 to 10 kHz and secondly, random perturbations with spectra corresponding to white noise; these spectra had various upper-frequency limits, mostly in the frequency range 0 to 10 kHz.

In all the tests, the picture material consisted of a display of colour bars; 95% saturation, 100% amplitude bars were employed for Test Series 2, 3 and 4 but 100% saturation, 100% amplitude bars were used in Test Series 1.

All the tests aimed to establish the magnitude of timing perturbations corresponding to picture impairment at the threshold of visibility. This threshold was defined as grade $1\frac{1}{2}$ on the 6-point impairment scale given in Table 1 for Test Series 2, and as grade $-\frac{1}{2}$ on the comparison scale given in Table 2 for Test Series 4. Both these definitions closely correspond to an impairment which is perceptible to 50% of observers and imperceptible to the remainder. In Test Series 2, impaired and unimpaired pictures were shown alternately, the degree of impairment being varied in an arbitrary manner. In Test Series 4, unimpaired and impaired pictures with various degrees of impairment were shown simultaneously on separate monitors, but the observers were not told which monitor displayed the impaired picture. In Test Series 1 and 3, the threshold was decided by allowing observers to adjust the amount of jitter to a level that they considered to be at the threshold of visibility.

Two different methods of introducing timing jitter were employed in the tests. In Test Series 2, 3 and 4, the jitter was introduced into an analogue video signal by means of electronically-variable delay-line, while in Test Series 1, the jitter was introduced by varying the timing of the clock pulses supplied to a digital-to-analogue converter handling an 8-bit p.c.m. video signal sampled at 13.3 MHz. Despite the considerable differences between these two techniques, their effects on the video signal are almost identical for the range of jitter frequencies examined.

A second difference in the test technique used for the

TABLE 1

Six-point impairment scale

1	Imperceptible
2	Just perceptible
3	Definitely perceptible but not disturbing
4	Somewhat objectionable
5	Definitely objectionable
6	Unusable

TABLE 2

Comparison scale

+3	A much better than B
+2	A better than B
+1	A slightly better than B
0	A the same as B
-1	A slightly worse than B
-2	A worse than B
-3	A much worse than B

various tests was that, in some, an unjittered colour burst was re-inserted into the video signal prior to P.A.L. decoding, the processing applied in each set of tests being indicated in Section 6. Experiments have indicated that the re-insertion of an unjittered burst has little effect on the displayed picture for jitter frequencies above about 100 Hz but, as mentioned in Section 3, burst re-insertion increases the picture impairment at lower jitter frequencies.

The viewing conditions in all the tests were similar but not identical, and corresponded approximately to those given in C.C.I.R. Recommendation 500.

The number of observers employed were 8, 10, 3 and 12 for Test Series 1, 2, 3 and 4 respectively.

6. Results of subjective tests

The main results obtained from all the tests for correctly adjusted static subcarrier phase are summarized in Figs. 2 and 3. Fig. 2 applies to sinusoidal jitter and Fig. 3 to random jitter. Test Series 4 did not include any tests on sinusoidal jitter.

The Natlock limit plotted on Fig. 2 has been explained in Section 3.

The peaks at 25, 50, 75 and 100 Hz in the response curve shown in Fig. 2 indicate that stationary patterns are less visible than moving ones. The tests performed at jitter frequencies above 100 Hz all employed moving patterns.

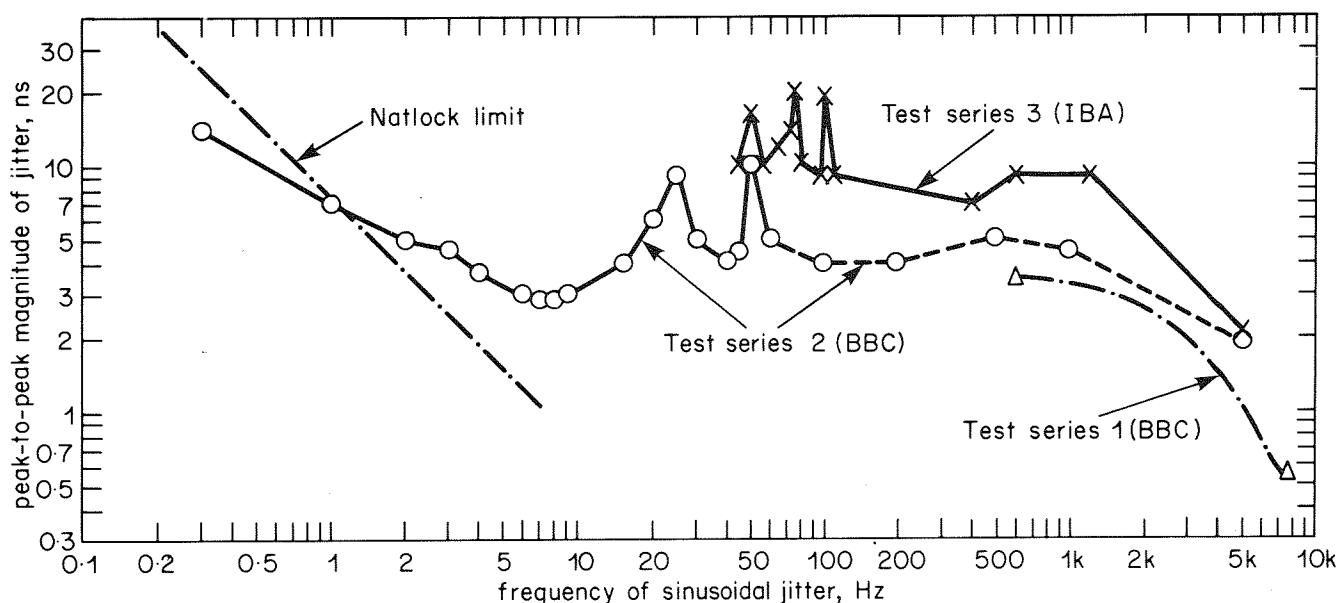


Fig. 2 - Magnitude of sinusoidal jitter causing impairment at the threshold of visibility on a colour bar display. Decoder accurately aligned

— 95% colour bars; burst re-inserted
 --- 95% colour bars; no burst re-inserted
 -.- 100% colour bars; burst re-inserted

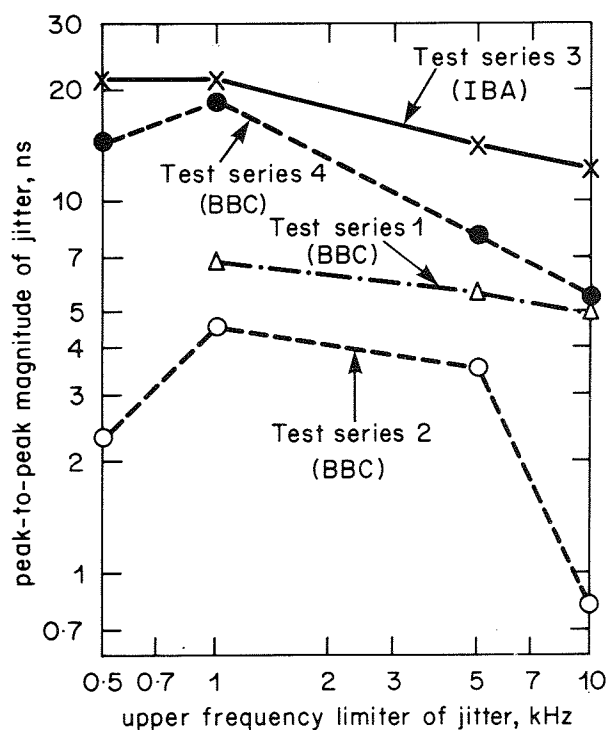


Fig. 3 - Magnitude of random jitter causing impairment at the threshold of visibility on a colour bar display. Decoder accurately aligned

— 95% colour bars; burst re-inserted
 --- 95% colour bars; no burst re-inserted
 -.- 100% colour bars; burst re-inserted

All the results obtained with the static subcarrier-phase deliberately misaligned are illustrated by Figs. 4, 5 and 6. Figs. 4 and 5 show results obtained during Test Series 1 and Fig. 6 gives results from Test Series 3. No other tests were performed with an incorrect static phase.

7. Discussion of results

With regard to tests with correctly adjusted static subcarrier-phase, Fig. 2 shows that the differences in the results obtained from the different Test Series for sinusoidal jitter are comparatively small, taking into account differences in test conditions and difficulties in determining the exact level of impairment corresponding to the threshold of visibility. For random jitter, however, the differences in the results shown in Fig. 3 are significantly greater and require further explanation.

One likely reason for the increased variation in results for random, as compared to sinusoidal, jitter is that it is not possible to make precise measurements of the peak-to-peak magnitude of a randomly varying signal.

In Test Series 1, 2 and 3, the peak-to-peak magnitude was estimated by visual examination of either (a) a display of the video waveform on an oscilloscope triggered by stable synchronising pulses, or (b) a display of the colour-subcarrier phase and amplitude on a vectorscope locked to a stable reference subcarrier.

In order to obtain a more precise measurement of the magnitude of the random jitter in Test Series 4, the r.m.s. magnitude of the jitter was deduced from the r.m.s. magnitude of the signal controlling the variable video-delay

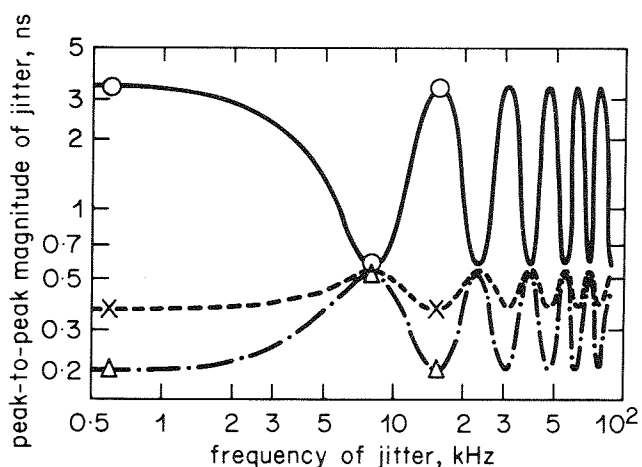


Fig. 4 - Magnitude of sinusoidal jitter causing impairment at threshold of visibility on 100% colour bar display at different static phase errors

○—○ 0° phase error
 X---X 16° phase error
 Δ—Δ 32° phase error

line, this signal magnitude being measured by a thermocouple device in a video signal-to-noise-ratio meter. In addition the peak-to-peak magnitude of the jitter was estimated in by both the methods described above. All these measurements were in good agreement bearing in mind that the ratio of the peak-to-peak (M) to the r.m.s. (σ) magnitudes of a random Gaussian signal is related to the probability (P) that the signal lies within the peak-to-peak limits M by the figures given in Table 3 on page 6.

The peak-to-peak values given in Fig. 4 for Test Series 4 are six times the r.m.s. values obtained from the noise meter, i.e. $M/\sigma = 6$. Table 3 shows that this value of M/σ corresponds to the inclusion of all but 0.3% of the noise within the peak-to-peak limits. As far as can be ascertained, a similar criterion for M/σ was employed for

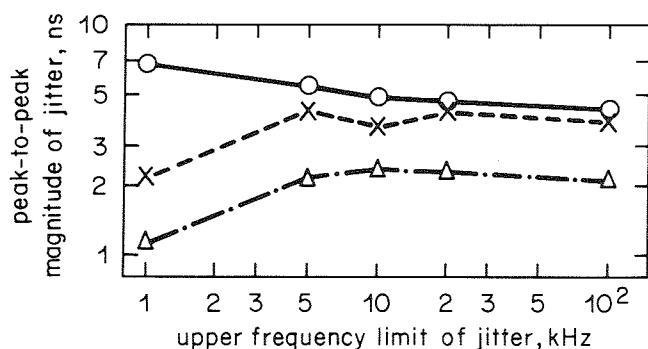


Fig. 5 - Magnitude of random jitter causing impairment at threshold of visibility on 100% colour bar display at different static phase errors

○—○ 0° phase error
 X---X 16° phase error
 Δ—Δ 32° phase error

Test Series 1 and 3 but, for Test Series 2, the peak-to-peak limits employed were more likely to have included about 90% of the timing variations corresponding to M/σ equal to about 3.5. Thus, the measurements of peak-to-peak jitter for Test Series 2 could have been about 5 dB lower than would have been obtained using the criteria adopted in the other Test Series.

In the remainder of this report it will be assumed that peak-to-peak measurements of jitter should include the maximum timing variations observed and therefore the criterion used in Test Series 1, 3 and 4 was correct.

Another possible reason for variations in the results obtained from different Test Series, for both sinusoidal and random jitter, is that the P.A.L. decoders employed in the various tests may not have been aligned identically in all respects. An indication of the accuracy of the decoders used in Test Series 1 and 2 can be obtained by comparing the results obtained for different settings of the static subcarrier phase (see Figs. 4, 5 and 6) with the theoretical calculations given in the Appendix. For example, Fig. 6 shows that, in Test Series 2, it was necessary to reduce the magnitude of sinusoidal jitter, in the frequency range 100 Hz to 1 kHz, by 12 dB at a static subcarrier phase-error (θ) of 15 degrees, whereas Fig. 7 in the Appendix indicates that this reduction should have been about 25 dB. In Test Series 1, the corresponding reduction in jitter was found to be 19 dB (see Fig. 4). No similar tests were carried out in Test Series 3 and 4.

The most probable reason for the significant difference between theory and the practical results obtained in Test Series 2 is that the decoder employed was misaligned in some respect other than the adjustment of static phase. If this assumption is correct the results of Test Series 2 for $\theta = 0^\circ$ would be too low. The smaller difference

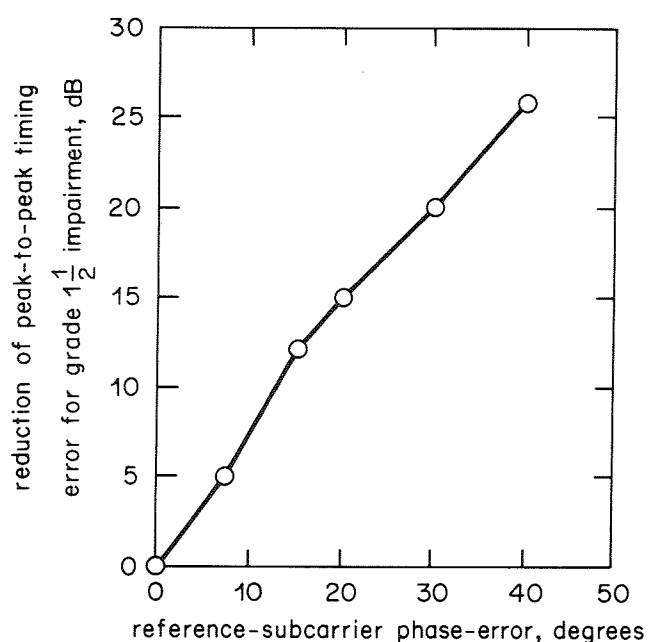


Fig. 6 - Effect of P.A.L.D decoder reference phase on the visibility of impairment of sinusoidal jitter

TABLE 3

Characteristics of Gaussian noise

M/σ	3	4	5	6	7
$20 \log_{10} M/\sigma$	9.5 dB	12.0 dB	14.0 dB	15.6 dB	16.9 dB
P	0.866	0.954	0.988	0.997	0.9999

between theory and practice for Test Series 1 indicates better alignment of the decoder.

A second point of interest regarding the effect of varying the static phase is that, while the difference between the results for sinusoidal jitter at $\theta = 0^\circ$ and $\theta = 16^\circ$ shown in Fig. 4 was 19 dB, the difference between the results at $\theta = 0^\circ$ and $\theta = 16^\circ$ for low bandwidth random jitter as shown in Fig. 5, was only about 10 dB. A possible reason for the smaller variation for random jitter compared to sinusoidal jitter is given in the Appendix, Section 11.1.

In order to provide an indication of the variation in results caused by difficulties in assessing the threshold of visibility of jitter, the results from Test Series 4 were analysed to find the jitter magnitudes at which 20% and 80% of observers correctly noted the presence of an impairment. The results obtained from this analysis differed from the results given for the impairment visible to 50% of observers by about ± 1.5 dB for random jitter with an upper frequency limit of 500 Hz and 1 kHz and by about ± 3 dB for upper frequency limits of 5 kHz and 10 kHz. It seems unlikely therefore that different methods of assessing the threshold of visibility could cause differences in results of more than ± 3 dB.

Taking all the known causes for experimental error into account, a reasonable estimate for the threshold of visibility of sinusoidal jitter, using a correctly aligned decoder, would appear to be about half-way between the results shown for Test Series 2 and 3 in Fig. 2 over the frequency range 50 Hz to 5 kHz, and about 3 dB higher than the results shown for Test Series 2 for jitter frequencies below 50 Hz. This estimate corresponds to peak-to-peak magnitudes in the range 5 ns to 8 ns for frequencies between 10 Hz and 1 kHz.

For random jitter, the results from Test Series 2 appear to be too low and the results from Test Series 1 are not entirely compatible with the other results because 100% colour bars were employed instead of 95% colour bars. Comparing Test Series 3 and 4, the only known instrumental cause for differences in the results obtained is that stable colour bursts were re-inserted prior to P.A.L. decoding in Test Series 3, but not in Test Series 4. This difference in the colour-burst processing may account for the fact that, in Test Series 4, the result for an upper frequency of 500 Hz is lower than the result for 1 kHz whereas in Test Series 3 the same results were obtained for both these bandwidths. Concerning differences in test conditions, Test Series 4 employed more observers

than Test Series 3, the numbers being 12 and 3 respectively, and also the technique for assessing the threshold of visibility was more precise for Test Series 4. Considering all these factors, a reasonable estimate for the peak-to-peak magnitude of random jitter visible to 50% of viewers would seem to be 20 ns for upper frequency limits of 500 Hz and 1 kHz falling to 10 ns and 7 ns for upper frequency limits of 5 kHz and 10 kHz respectively. These figures apply to correct adjustment of the static subcarrier phase.

The figures given above are somewhat unrealistic, however, since significant errors in the alignment of P.A.L. decoders are quite common in domestic television receivers. B.R.E.M.A. have been considering this matter and have tentatively suggested that manufacturers will have difficulty in maintaining the accuracy of the static subcarrier-phase to a closer tolerance than $\pm 15^\circ$ including an allowance for long-term drifts. This tolerance of $\pm 15^\circ$ would mean that the limits for acceptable jitter would have to be reduced by perhaps 20 dB for sinusoidal jitter and 10 dB for random jitter. It should be noted that these figures for misaligned decoders are based on rather inconclusive evidence, particularly with regard to random jitter, for which the reduction of only 10 dB for misalignment appears to be too small, a figure of at least 12 dB being more likely to be correct.

8. Recommendations for further work

It is recommended that further tests should be carried out on the effects of random jitter with misaligned decoders. This work is important since, in practical situations, decoders are unlikely to be perfectly aligned and the nature of the jitter produced in a broadcasting network is likely to be more random than sinusoidal. The only relevant results obtained so far for random jitter with misaligned decoders are illustrated in Fig. 5. These results do not provide a very satisfactory basis for a specification for jitter tolerances in broadcasting networks because of a number of factors, including:

- An insufficient number of tests was performed.
- The test picture employed was 100% colour bars which is about the most critical picture which can be used, whereas C.C.I.R. Recommendation 500 indicates that test pictures 'should be more uncritical than average pictures, although not unduly so'. 95% colour bars are more suitable in this connection.

- (c) Uncertainties exist concerning the measurement of the peak-to-peak magnitude of the random timing variations.

The difficulties in defining the peak-to-peak magnitude of random variations indicates that, in any further work on random jitter, more consistent results would be obtained if the r.m.s. magnitude of the jitter were measured instead of its peak-to-peak value. Peak-to-peak measurements are probably more relevant, however, in any specification for allowable jitter in a broadcasting network, since it is difficult to measure the r.m.s. magnitude of jitter produced in practice by video-tape recorders, digital transmission links etc. In order to achieve a compromise between these requirements, it is recommended that the r.m.s. magnitude of the jitter should be measured whenever possible and then these measurements should be converted to peak-to-peak values by multiplying by a factor of six. If r.m.s. measurements are not possible then the peak-to-peak measurements should include the maximum timing perturbations observed.

- (d) The decoder may not have been correctly aligned in respect of adjustments other than the setting of the static subcarrier-phase. In any further tests, the alignment of the decoder should be very critically examined in order to ensure that the results obtained are not significantly affected by the various forms of decoding error mentioned in Section 2.

9. Conclusions

The tests discussed in this report indicate that the timing instability or jitter in a broadcast P.A.L. video signal will have a negligible effect on the picture quality provided by a perfectly aligned P.A.L. decoder if the peak-to-peak jitter does not exceed 20ns for random perturbations or about 8ns for sinusoidal perturbations. These tolerances are applicable to the range of jitter frequencies likely to be introduced by both video-tape recorders and digital transmission links, i.e. to jitter

frequencies below about 2 kHz.

A further tightening of the specification for allowable jitter in a broadcast network should be made, however, in order to allow for errors in the transmitted mean burst-phase (specified for System I at ± 2 degrees) and to allow for imperfect alignment of P.A.L. decoders, particularly with regard to the adjustment of the static phase of the re-generated reference subcarrier. B.R.E.M.A. have tentatively suggested that, in the long term, static phase errors of up to ± 15 degrees might be found in the decoders of domestic television receivers. From rather inconclusive tests, it appears that the effect of these constraints is to reduce the allowable jitter by 12 dB and 20 dB for random and sinusoidal jitter respectively. The suggested final values for a target specification for allowable jitter in a broadcast signal are 5ns peak-to-peak for random perturbations and 0.8ns peak-to-peak for sinusoidal perturbations.

It should be noted that at jitter frequencies below about 100 Hz, the allowable jitter depends on whether a stable colour-burst is re-inserted in the jittered video signal and on whether the jittered video signal is being synchronised with a second video signal. The effects of these processing operations is discussed in Section 3. For jitter frequencies above about 100 Hz, burst re-insertion and synchronising operations have little effect on the permissible magnitude of the jitter.

10. References

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2. CHEW, J.R. and STEBBINGS, D.W. 1975. Specification of the timing stabilities of broadcast monochrome and P.A.L. colour television signals. B.B.C. Research Department Report No. 1975/14.
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11. APPENDIX

11.1. Theoretical analysis of effect of misalignment of static subcarrier phase

Theoretical calculations based on Fig. 1 show that for a given peak-to-peak variation in the magnitude of the colour-difference signals (i.e. $V_J/\cos \theta = \text{a constant}$), the peak-to-peak magnitude of the jitter (J) measured in nanoseconds decreases with increasing static subcarrier phase error (θ) in accordance with the expression

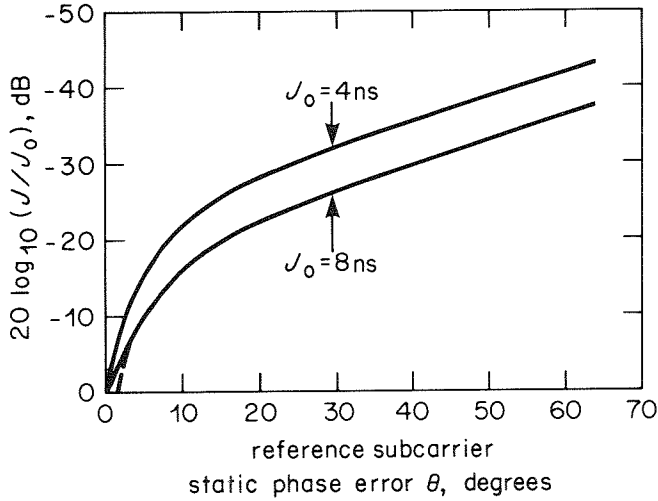


Fig. 7 - Theoretical effect of static phase errors on magnitude of sinusoidal jitter causing a given peak-to-peak variation in the magnitude of colour-difference signals.

— Plot of Eqn 1 corrected to pass through origin
 - - - Uncorrected plot of Eqn 1 for $J_0 = 8 \text{ ns}$

$$J = \frac{\pi f_{sc} J_0^2}{4 \tan \theta} \cdot 10^{-3} \quad (1)$$

where f_{sc} is the colour subcarrier frequency in MHz and J_0 is the value of J at $\theta = 0^\circ$. This expression assumes that the variations in the colour-difference signals are small (e.g. $< 3\%$) and also it becomes inaccurate near $\theta = 0^\circ$ as discussed below.

Plots of $20 \log_{10} J/J_0$ against θ derived from Eqn (1) are shown in Fig. 7 for peak-to-peak colour difference signal variations of 0.115% and 0.620%, these being equal to the variations obtained with $J_0 = 4 \text{ ns}$ and 8 ns respectively. The results of tests on jitter indicate that these magnitudes of colour-difference variations produce picture impairments close to the threshold of visibility

* For small variations in the colour difference signals, it is easy to show that

$$V_{J_0} = 1 - \cos(\pi f_{sc} J_0 \times 10^{-3}) \quad (2)$$

$$V_J = 2\pi f_{sc} J \sin \theta \times 10^{-3} \quad (3)$$

Using the relationship $\cos x = (1 - x^2/2)$ for small values of x , Eqn (3) becomes

$$V_{J_0} = \frac{1}{2} (\pi f_{sc} J_0 \times 10^{-3})^2 \quad (4)$$

Using Eqns (3) and (4) and the required relationship that $V_J/\cos \theta = V_{J_0} = \text{constant}$ gives Eqn (1).

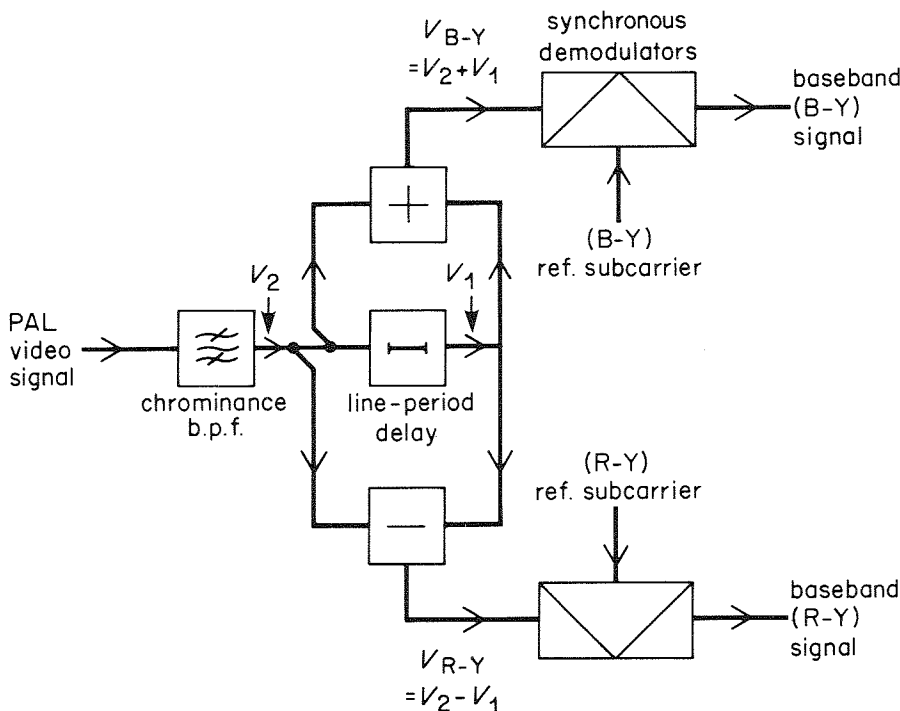


Fig. 8 - Block diagram of a delay-line P.A.L. decoder

for low-frequency sinusoidal jitter. Eqn (1) becomes inaccurate for very small values of θ and more accurate results are obtained for these values of θ from the knowledge that the curves in Fig. 7 must pass through the point $20 \log_{10} J/J_0 = 0$ at $\theta = 0^\circ$.

It should be noted, that the curves of Fig. 7 are likely to correspond to lines of constant visibility of impairment for sinusoidal jitter but not for random jitter. The difference between sinusoidal and random jitter may be explained by reference to the colour-difference waveforms with peak-to-peak magnitudes V_{Jo} and V_J shown in Fig. 1. For random jitter, the V_{Jo} waveform would be roughly similar to a half-way rectified version of the V_J waveform. As a consequence of this change in waveform, curves of constant peak-to-peak magnitude as plotted in Fig. 7 do not necessarily correspond to curves of constant visibility. On the other hand, for low-amplitude sinusoidal jitter, although the frequency of the V_{Jo} waveform is twice that of the V_J waveform, both waveforms are very nearly sinusoidal. Additionally, the results given in Section 6 indicate that frequency doubling has little effect on the visibility of low-frequency sinusoidal jitter and therefore, for this form of jitter, the curves in Fig. 2 should correspond quite closely to curves of constant visibility. This is relevant in the analysis of results obtained from subjective tests on jitter (see Section 8).

11.2. Effect of repetition frequency of jitter on the form of the resulting picture impairment

In a delay-line P.A.L. decoder, the two colour difference signals, V_{B-Y} and V_{R-Y} are first separated by adding and subtracting the input and output signals V_1 and V_2 of a one-line delay as shown in Fig. 8 where $|V_1| = |V_2|$ in areas of uniform chrominance.

Assuming no change in chrominance on successive

lines and that no jitter is present, the relative phases of the subcarrier at the input and output of the delay line are symmetrical about the B-Y axis as shown in Fig. 9(a) and the phase of outputs of the adder and subtractor are as shown in Fig. 9(b). (See Page 10).

In the presence of jitter which has a repetition frequency close to $n f_L$, where $n = 0, 1, 2$, etc. and f_L is the line frequency of the video signal, any phase shifts in V_1 and V_2 will be equal and in the same direction; this is shown in Fig. 9(c) where V_1 and V_2 are shifted by ϕ to become V_1^1 and V_2^1 and $|V_1| = |V_2| = |V_1^1| = |V_2^1|$. The resulting outputs from the adder and subtractor are now as given by V_{B-Y}^1 and V_{R-Y}^1 in Fig. 9(d) where the magnitude of these signals are equal to V_{B-Y} and V_{R-Y} . Assuming that the static phase of the reference subcarrier fed to the synchronous demodulators are correctly aligned along the R-Y and B-Y axes, the outputs from the demodulators will both be reduced by a factor of $\cos \phi$; as a result only the saturation of the colours is altered, the hue remaining unaltered; a similar but static effect is obtained if the reference subcarrier is misaligned providing that its components fed to the two demodulators are in quadrature. The combination of static and jitter effects will be as discussed in Section 2 and Fig. 1.

In the presence of jitter which has a repetition frequency close to $(n + \frac{1}{2})f_L$, the instantaneous phase-shifts of V_1 and V_2 will be equal and opposite as indicated by V_1'' and V_2'' , in Fig. 9(e). Since the angle between V_1'' and the B-Y axis is now equal and opposite to that between V_2'' and the B-Y axis and also $|V_1| = |V_1''| = |V_2| = |V_2''|$, it can be seen directly from Fig. 7(e) that only the hue of the chrominance signal has been changed to correspond to a subcarrier phase of $(\theta + \phi)$ instead of θ , the saturation remaining unaltered. For completeness, the form of the outputs from the adder and subtractor are indicated by V_{R-Y}'' and V_{B-Y}'' in Fig. 9(f).

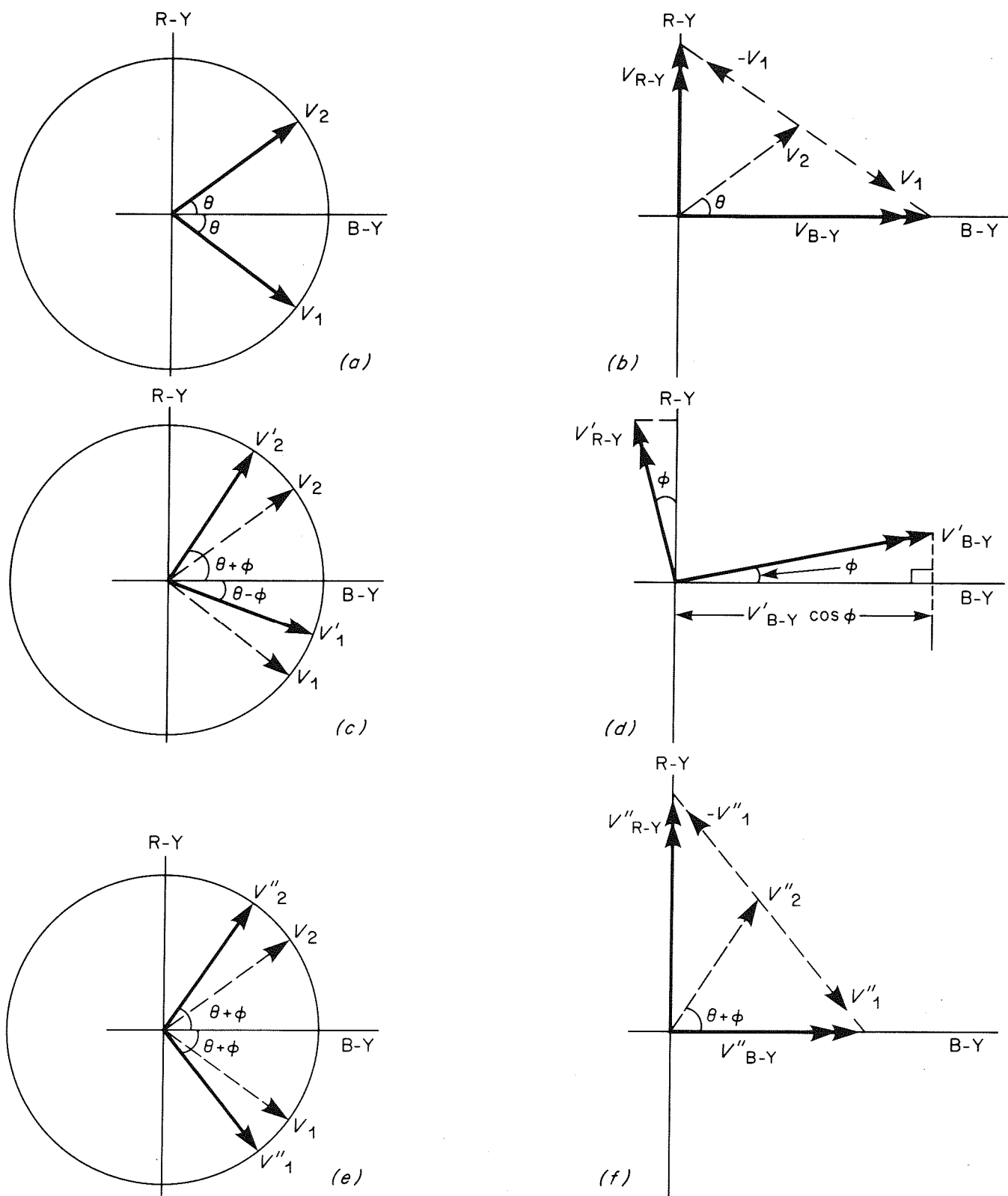


Fig. 9 - Effect of different jitter frequencies on the phase and amplitude of the chrominance signals at the inputs and outputs of the adder and subtractor in a delay-line P.A.L. decoder

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|-------------------------------------|---|-------------------------------------|-------------------------|
| (a) Inputs of adder and subtractor | } No jitter | (c) Inputs of adder and subtractor | } Jitter freq = $n f_L$ |
| (b) Outputs of adder and subtractor | | (d) Outputs of adder and subtractor | |
| (e) Inputs of adder and subtractor | } Jitter freq = $(n + \frac{1}{2}) f_L$ | (f) Outputs of adder and subtractor | |

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